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INVESTIGATIONS INTO METHANE ACCUMULATION IN COAL STORAGE SILOS

R.J. Kolada
Calgary Coal Research Laboratory

December 1984

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32 pp

ENERGY RESEARCH PROGRAM
COAL RESEARCH LABORATORIES
DIVISION REPORT ERP/CRL 84-41(TR)

MICROMEDIA
MAR 15 1985

INVESTIGATIONS INTO METHANE ACCUMULATION IN COAL STORAGE SILOS

by

R.J. Kolada*

ABSTRACT

The ventilation systems of coal storage silos are normally capable of rapidly dispersing any accumulations of methane in the atmosphere above the coal pile surface. However, the results of an investigation which is presented in this report show that hazardous concentrations of methane can accumulate within the coal pile.

Methane trapped within the coal pile is released into the atmosphere of the loading gallery when coal is discharged from a silo. If the methane released is of a flammable concentration it is necessary to ventilate the gallery to reduce the risk of an ignition. This report proposes a simple test, which, after further investigations may prove to be an effective method to calculate gallery ventilation requirements.

*Research Scientist, Calgary Coal Research Laboratory, CANMET, Energy, Mines and Resources, Calgary, Alberta.

INVESTIGATIONS PORTANT SUR LES ACCUMULATIONS DE MÉTHANE DANS LES SILOS D'EMMAGASINAGE DU CHARBON

par R.J. Kolada

RÉSUMÉ

Les silos d'emmagasinage du charbon ont en général la capacité de disperser rapidement toute accumulation de méthane se trouvant à la surface des amas de charbon. Cependant, les résultats d'une investigation présentée dans ce rapport indiquent que des concentrations dangereuses de méthane peuvent s'accumuler à l'intérieur des amas de charbon.

Le méthane piégé est libéré dans l'atmosphère de la galerie de chargement lorsque le charbon est évacué du silo. Si le méthane libéré provient d'une concentration inflammable, il est nécessaire d'aérer la galerie afin de réduire les risques d'allumage .Dans le présent rapport on suggère un essai facile lequel, après de nouvelles investigations peut s'avérer une méthode efficace pour calculer les besoins en aérage de la galerie.

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*Chercheur scientifique, Laboratoire de recherche sur le charbon de Calgary, Énergie, Mines et Ressources, Calgary, Alberta.

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1. INTRODUCTION

A recent explosion within a coal storage silo in western Canada was attributed to an accumulation of methane (1). In order to determine the best approach for reducing or eliminating any further risk of silo explosions, consultations were held between the British Columbian Mines Inspectorate (coal), CANMET and several western Canadian coal mine operators. It was agreed that this objective could be accomplished more effectively if a preceding investigation into the occurrence of methane accumulations in coal silos were to be conducted. This report details the methods, results and conclusions of this investigation.

2. THE FUNCTION OF COAL SILOS

Coal silos may be classified by their function into two types: raw coal silos and clean coal silos. Raw coal silos are used to store coal from the mining site before it is passed to the preparation plant. The supply of coal from the mining site is often irregular. However, the preparation plant only works efficiently if it receives an even, continuous flow of coal. Raw coal silos therefore act as a buffer to even the fluctuations in supply.

Clean coal silos are used to store coal after it has passed through the preparation plant. They are normally built over or next to railway lines so they can discharge into unit trains for transportation to customers.

Both clean and raw coal silos invariably have closed tops as this provides some useful benefits. Open coal storage piles can be environmentally unacceptable due to the amount of coal dust that is released into the atmosphere. By using closed top silos for storage, any coal dust generated can be prevented from entering the atmosphere.

Closed top silos also prevent precipitation from falling on the stored coal which could otherwise cause physical and chemical degradation of the coal and make it difficult to handle (discharge blockages are a particular problem).

3. COAL SILO VENTILATION

Coal can release significant quantities of methane especially if it has been recently mined. Therefore coal silos are always ventilated to prevent hazardous concentrations of methane from accumulating in the silo.

The various types of coal silo ventilation systems that are used may be classified into two groups depending on whether, natural or artificial ventilation is used.

3.1. NATURALLY VENTILATED SILOS

All open top silos are naturally ventilated by the action of wind blowing horizontally across the top and so inducing turbulent mixing and dilution of any methane in the upper section of the silo (Fig. 1a). This system suffers a number of disadvantages as already described, e.g. coal degradation, discharge blockages, and dust emission. To solve the problems caused by precipitation a roof may be supported over the silo (Fig. 1b), or the silo can have a closed top with side ports (Fig. 1c).

The ventilation efficiency of the system depicted by Fig. 1c is considered to be insufficient and is rarely recommended. In contrast the other two systems, Figs. 1a and 1b, have been found by experience to be exceptionally effective. However, all these methods can be environmentally unacceptable due to the uncontrolled release of dust and are falling into disfavour.

3.2. ARTIFICIALLY VENTILATED SILOS

By ventilating a silo with fans the flow of air into, and from the silo, can be regulated. Hence the flowrate of dust entrained in the ejected air may, to a large extent, be controlled. If however regulation does not reduce dust emission to an environmentally acceptable level a dust filtering unit can be installed.

Figures 2a and 2b show two common fan ventilation systems. In Fig. 2a, air is exhausted to atmosphere by a fan connected to a dust hood that is centrally located on the silo. The fresh air is drawn into the silo radially from ports surrounding the circumference of the silo. In Fig. 2b, air is exhausted to atmosphere from one side of the silo by a fan and fresh air is drawn through ports on the other side.

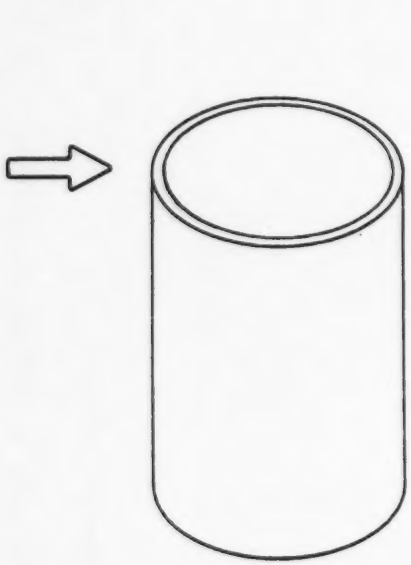


Fig. 1a - Open

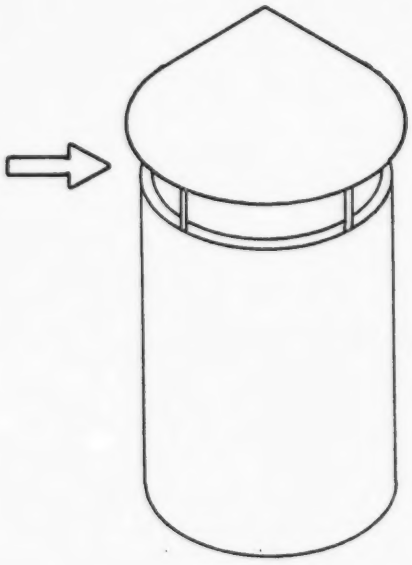


Fig. 1b - Raised roof

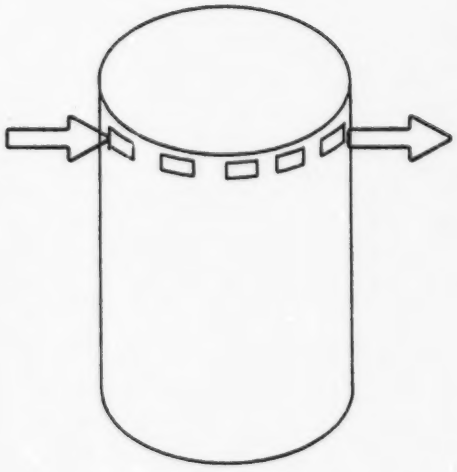


Fig. 1c - Closed, using side ports

Fig. 1 - Methods of ventilating silos using natural ventilation

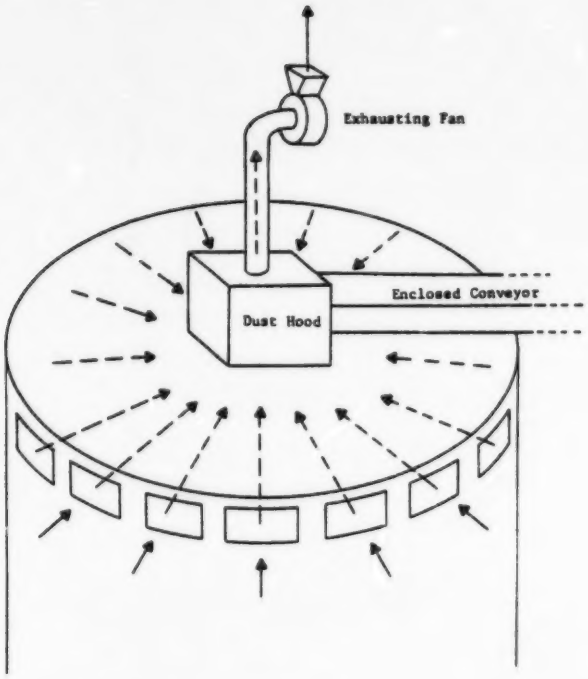


Fig. 2a - Radial flow

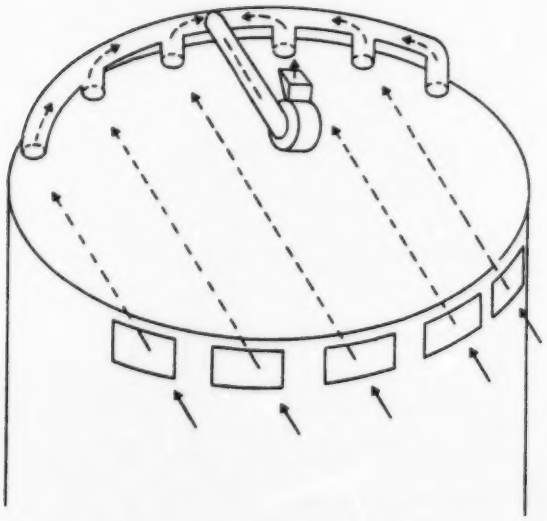


Fig. 2b - Parallel flow

Methods of ventilating silos using artificial ventilation

4. PREVIOUS INVESTIGATIONS OF METHANE ACCUMULATIONS IN COAL SILOS

Methane has a density of approximately half that of air. Due to this natural buoyancy there is a danger when methane is released in an unventilated silo that it will rise to the roof of the silo and accumulate in pockets or layers.

Current coal silo ventilation systems provide a maximum airflow rate and hence a maximum rate of methane dilution, at the top of the silo. The ventilation and dilution rate decreases further down the silo but it is usually found to be adequate to disperse any methane accumulations between the roof and near to the coal pile surface.

Figure 3 is reproduced from a U.S. Bureau of Mines report entitled, "Methane emissions from gassy coals in storage silos" (2). It shows a graph of methane concentrations plotted against the depth from the silo roof at which they were measured. The measurements were taken near the centre axis at three metre intervals from the silo roof down to the surface of the coal.

Examination of this graph shows that methane dilution is more effective near the silo top and decreases with depth. However the maximum methane concentrations found in the region between the silo roof and near to the coal pile surface were less than 0.8%.

The Bureau of Mines report also includes a few interesting observations which are reproduced below:

a) When taking the measurements that are shown on Fig. 3 it was discovered that: "If the end of the sampling tube actually touched the surface of the coal pile concentrations of a few percent were often measured".

b) "To investigate the methane concentration in the coal pile, a section of polyethylene tubing was extended halfway down into an empty closedtop silo, where it was buried by coal as the silo was filled over an 8-hour period. About 2 hours after the silo was filled, a methane concentration of about 14 pct was measured in the coal pile. The methane concentration above the coal pile was les than 0.5 pct. It appears that although the methane concentration above the coal is low, large concentrations in the coal pile may exist".

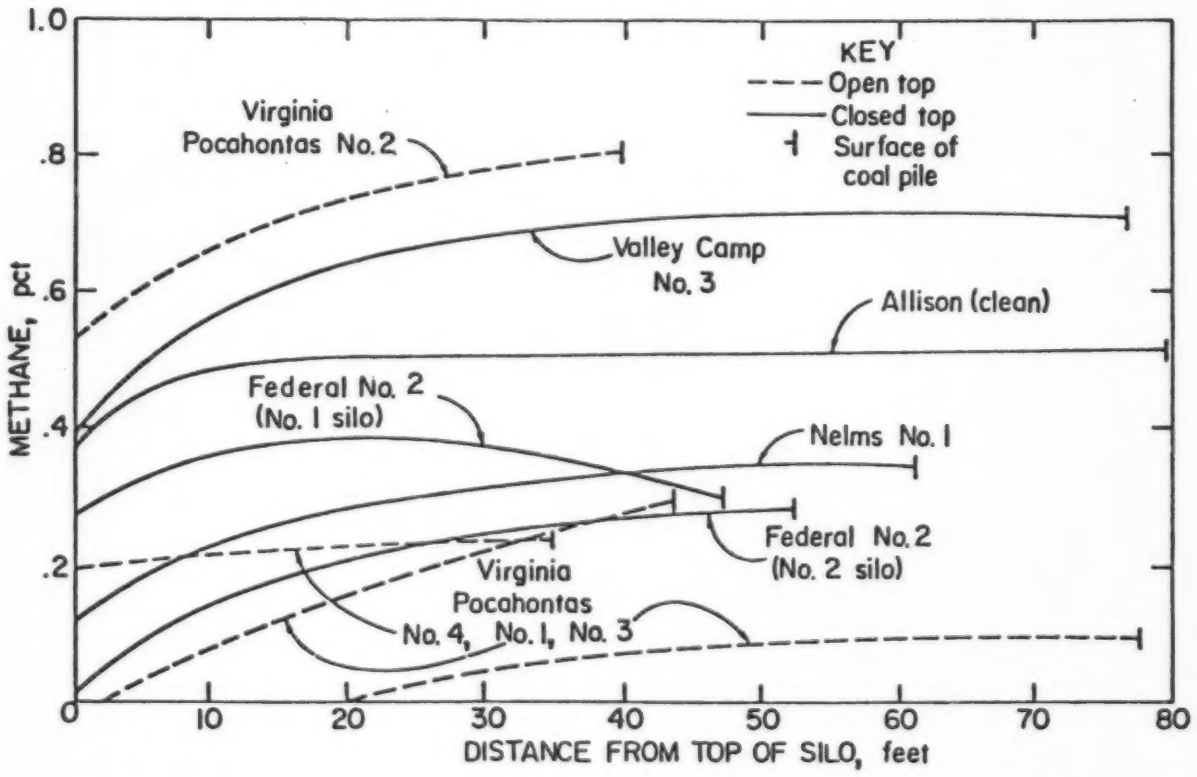


Fig. 3 - Methane concentration gradients in coal silos. After USBM Report 2

5. THE SITE OF THE INVESTIGATION

The Westar, Elkview Coal Preparation Plant is situated in the Southeast of British Columbia. The plant processes coal from both opencast and underground mines. Truck and shovel methods are used at the opencast mine which produced 5.7 million tonnes in 1983. The underground mine uses both hydraulic and room and pillar methods producing one million tonnes in 1983. Coal from both mines is mined from one seam which is classified as low to medium volatile bituminous in rank and it is exported for use in the metallurgical industry.

The plant has four, 2000 t capacity raw coal silos and four 13 000 t capacity clean coal silos.

6. EQUIPMENT

6.1. TUBE BUNDLE

Figure 4 depicts the tube bundle sampling system used during the investigations. By using a valve system and two air pumps as shown it is possible to rapidly sample the air being drawn into every tube. One of the pumps draws air through all of the tubes and exhausts to atmosphere. The other pump draws air from the tube to be sampled and passes it to the methanometers. This avoids any delay in waiting for each tube to be flushed out with the air to be sampled.

All of the methanometers were of the infra-red type. The 0-100% methanometer was graduated at 1.0% intervals and the 0-5% methanometers were graduated at 0.1% intervals. Two methanometers were used in testing the 0-5% range because two were available and could be used to check each other for span drift. Cylinders of compressed mixtures of methane and air of accurately known concentration were used check the calibration of the instruments.

The length and number of tubes in the tube bundle may be varied. For example; when investigating the region between the silo roof and just above the coal pile surface a bundle of six tubes sampling at three metre intervals was used.

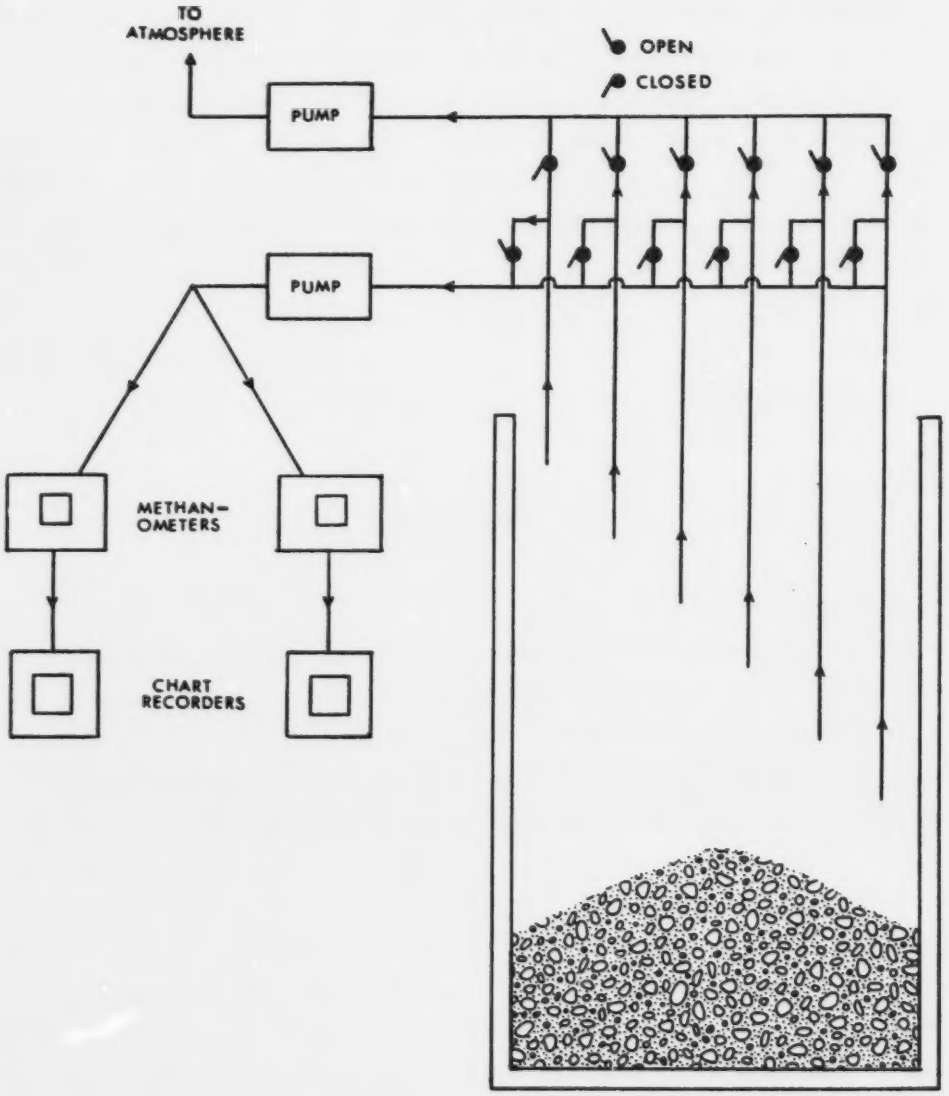


Fig. 4 - Tube bundle sampling system

6.2. METHANE DESORPTION APPARATUS

While testing the air inside a silo for methane, coal samples were also taken from the silo loading conveyor for methane desorption testing. The purpose of this testing was to determine the rate at which methane is released from the coal stored in the silo.

Figure 5 depicts the apparatus used for the methane desorption tests. The coal sample is placed in an air-tight container and the volume of methane released is measured via a tube connected to a graduated cylinder filled with water. When taking readings the height of the reservoir is adjusted so that the water levels in the cylinder and reservoir are the same. This ensures the gases in the cylinder and sample container are at atmospheric pressure.

7. RESULTS

Investigations revealed that there are three regions in a coal silo where the air may have significantly different concentrations of methane. These regions are listed below:

a) Between the roof of the silo and approximately a quarter of a metre above the coal pile surface.

b) Between the surface of the coal pile and approximately a quarter of a metre above the coal pile surface.

c) Below the surface of the coal pile i.e. the air trapped in the interstices between the coal lumps.

7.1. METHANE CONCENTRATIONS BETWEEN THE ROOF AND JUST ABOVE THE COAL PILE SURFACE

To obtain measurements of methane concentration in the region between the silo roof and just above the coal pile surface, the complete tube bundle system as shown by Fig. 4 was used. The opening of each tube was set at three metre intervals and measurements were made using both of the zero to 0.5% range methanometers.

In both raw and clean coal silos no measureable concentration of methane was recorded in the region.

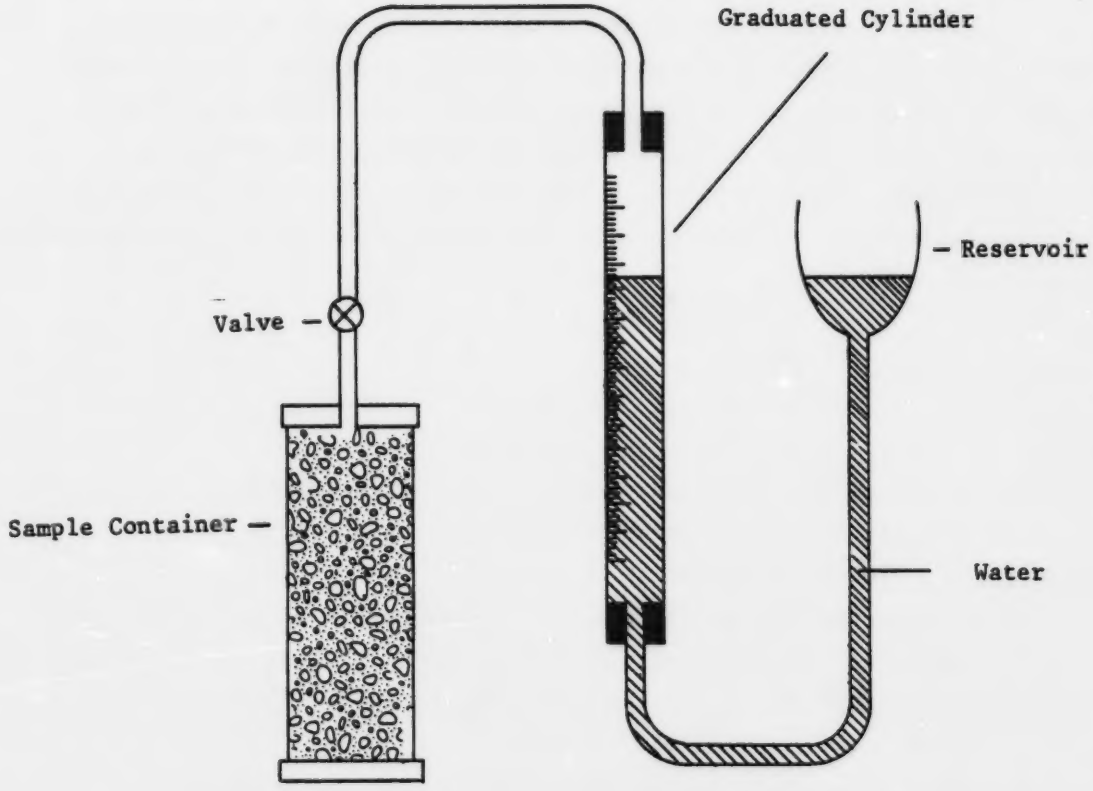


Fig. 5 - Methane desorption apparatus

This fact indicates that the silo ventilation system in use, which is of the type depicted by Fig. 2a, was capable of preventing methane accumulations.

7.2. METHANE CONCENTRATIONS IN THE REGION BETWEEN THE COAL PILE SURFACE AND APPROXIMATELY 0.25 M ABOVE IT

To obtain measurements of methane concentration in this region the same equipment as shown by Fig. 4 was used except that only a single tube was used for sampling.

While the silos were not discharging coal it was possible to rest the end of the sampling tube on the surface of the coal pile. This resulted in measurements of methane concentration which rapidly fluctuated between approximately 0-1% in raw coal silos and 0-2% in clean coal silos. By raising the end of the sampling tube approximately 0.25 of a metre, measureable concentrations of methane ceased to be detected in both clean and raw coal silos.

When the silos were discharging the surface of the coal pile forms a funnel shape and becomes semi-mobile. A dust filter is attached to the end of the sampling tube and if this is rested on top of the coal pile when the silo is discharging it rapidly becomes buried.

Consequently, when sampling in this region it is necessary to continually raise and lower the tube so that the coal pile surface can be felt by the change in weight of the tube and so that the end can be prevented from penetrating into the coal pile. By using this method when the silos were discharging, methane concentrations in the range of approximately 1-3% were recorded at the coal pile surface in raw coal silos and approximately 2-6% at the coal pile surface of clean coal silos. By raising the end of the sampling tube approximately 0.25 m above the coal pile surface measureable methane concentrations again ceased to be detected.

7.3. METHANE CONCENTRATIONS BELOW THE SURFACE OF THE COAL PILE

For sampling the air within the coal pile a single tube was used for each test. Special precautions were necessary to guarantee that the tube would automatically disconnect itself from the instrumentation when under tension. This provision is required because it is impossible to remove the tube from the coal pile when it buried and so the tube will be dragged into the silo upon discharging.

7.3.1. Raw Coal Silos

Figure 6 shows the rise in methane concentration with time in the coal pile of a raw coal silo. Measurements were recorded from the time the end of the tube was first buried. The tube was gradually buried to a depth of 15 metres which took approximately 40 minutes. Measurements were terminated when processing operations required the silo to discharge.

While methane concentrations in the coal pile were being measured a sample of the coal being deposited in the silo was obtained for methane desorption testing. The methane desorption testing was performed immediately the sample was obtained and simultaneously with the measurement of methane concentration in the coal pile.

The volume of methane released from the sample is plotted on Fig. 7 against time. By using this data it is possible to attempt a prediction of the rise of methane concentration in the coal pile. The rest of this section demonstrates the calculations necessary to make this prediction. For example:

Bulk density is defined as the total weight of solid material per unit volume. The average bulk density of the broken coal within the silo was given by the mine operators as approximately 800 kg/m^3. The average specific gravity of the coal was also given by the mine operators as 1.36, hence a solid one metre cube block of coal with no air spaces would weigh 1360 kg. Consequently the percentage volume of solid coal in the silo coal pile is given as:

$$800/1360 \times 100\% = 59\%$$

which leaves 41% of the coal pile volume as air spaces.

Consider a one metre cube of the coal pile. The volume of methane released into this cube, which contains an average of 800 kg of coal, may be calculated from the methane desorption data shown by Fig. 7. For example after 30 minutes one kilogram of coal releases approximately 13 cm^3 of methane. Therefore in a one metre cube of the coal pile

$$\frac{13 \times 800}{1000} = 10.4\ell$$

10.4ℓ of methane should be released after 30 minutes.

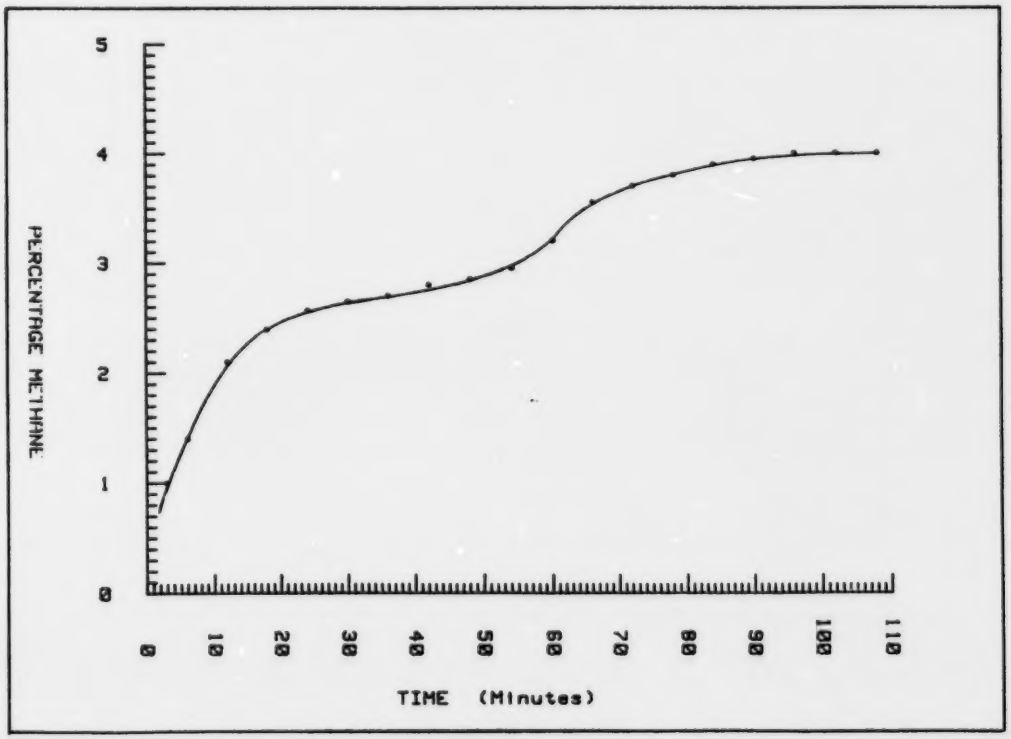


Fig. 6 - The rise in methane concentration within the coal pile of a raw coal silo (test 1)

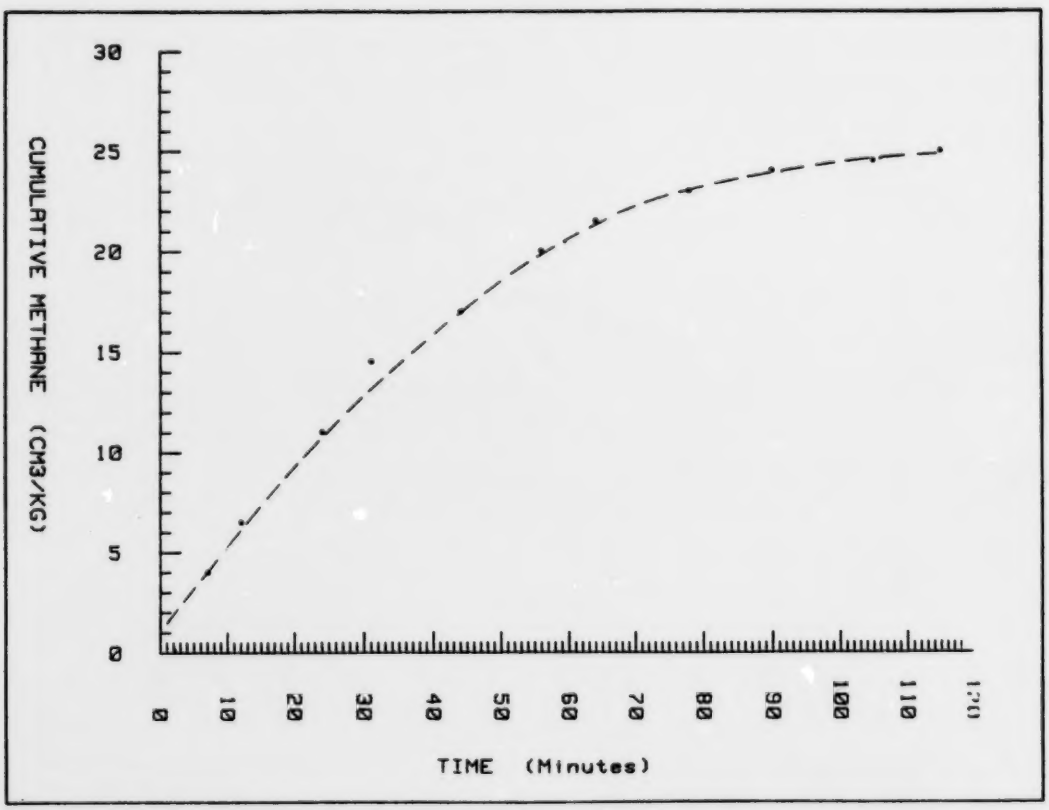


Fig. 7 - The volume of methane released, plotted against time, from a coal sample obtained during test 1.

Let M (as calculated above) be the volume of methane released into one cubic metre of the coal pile. 41% of the coal pile is air space hence in one cubic metre there is 410ℓ of air. Since methane concentration (C) is given by

$$C = \frac{\text{volume of methane}}{\text{volume of air + volume of methane}} \times 100\%$$

then the concentration of methane in the coal pile is given by

$$C = \frac{M}{M + 410} \times 100\% \ .$$

Still using the above example, after 30 minutes the concentration in the coal pile should be

$$\frac{10.4}{10.4 + 410} \times 100\% = 2.5\% \ .$$

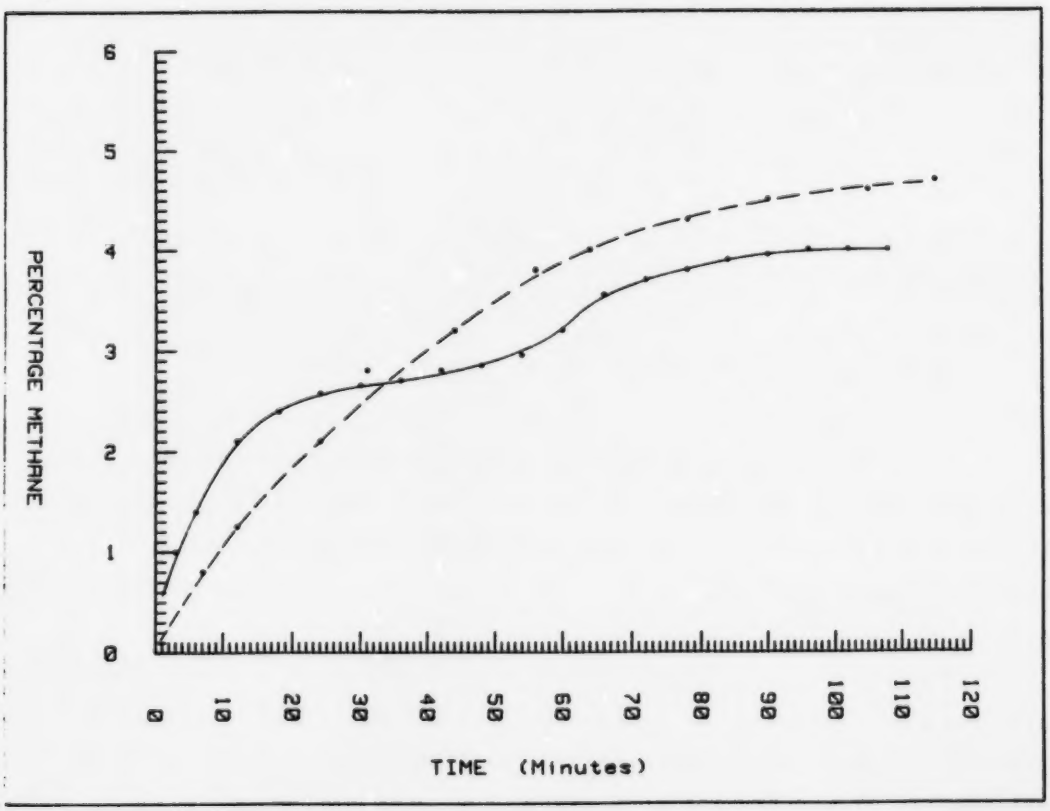
By using the methane desorption data in this calculation it is possible to predict the approximate methane concentration in the coal pile. This has been done using the methane desorption data shown on Fig. 6 and is shown as a dashed curve on Fig. 7. For comparison the actual concentrations measured are shown as a continuous curve on Fig. 8.

Figures 9 and 10 also show the predicted and actual coal pile methane concentrations for two other tests. For these tests the tubes were buried to depths of 10 m and 11 m respectively. The time taken to bury the tubes was approximately 25 minutes for both tests.

7.3.2. Clean Coal Silos

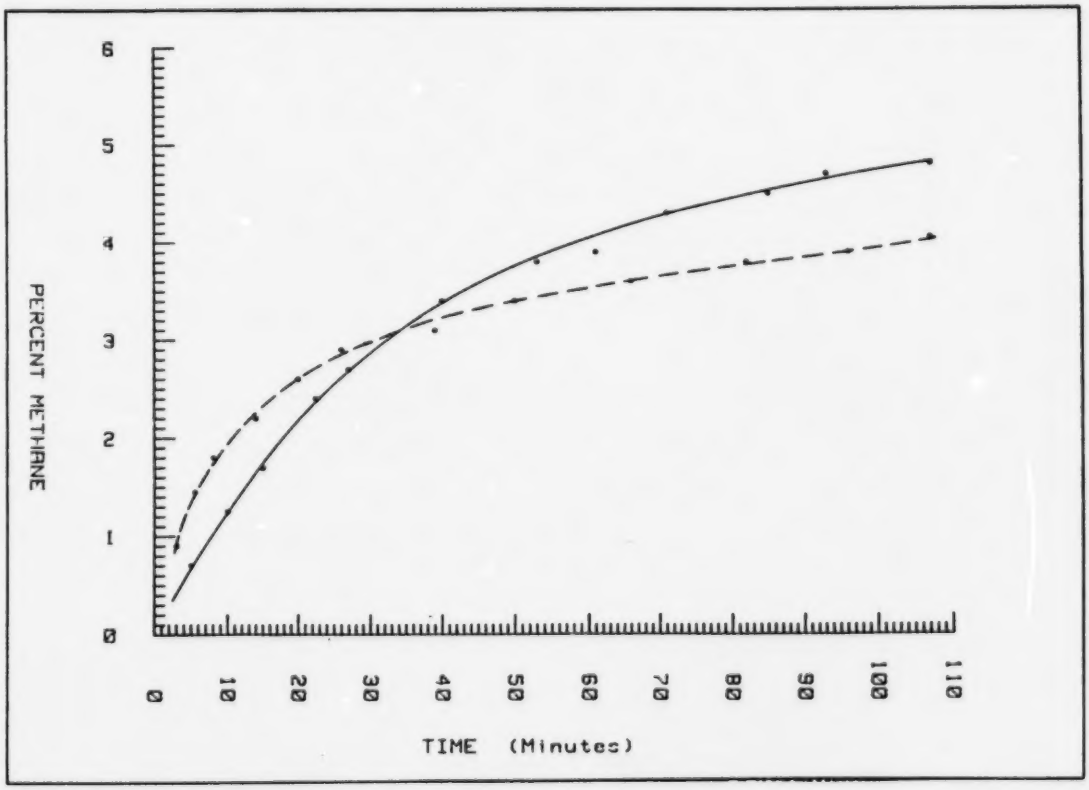
The same experimental procedure for testing the raw coal silos was used in testing the clean coal silos, except for a slight modification to the method of obtaining the methane desorption data.

Before coal is deposited in the clean coal silos it passes through a fluidized bed drier to reduce the moisture content. This has the effect of raising the temperature of the coal to approximately 40°C. Coal placed inside the methane desorption sample container at this temperature would be likely to



- - - - Predicted
_____ Measured

Fig. 8 - Comparison of the predicted and measured methane concentrations within the coal pile of a raw coal silo (test 1)



- - - - Predicted
_____ Measured

Fig. 9 - Comparison of predicted and measured methane concentrations within the coal pile of a raw coal silo (test 2).

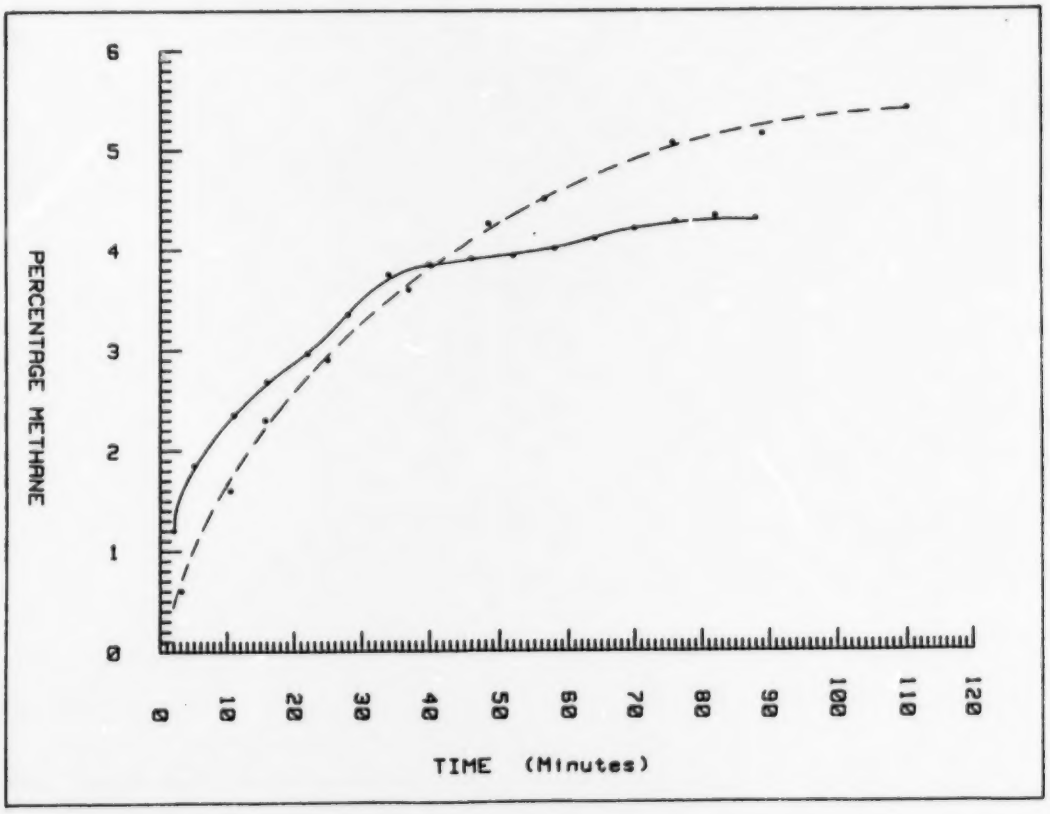
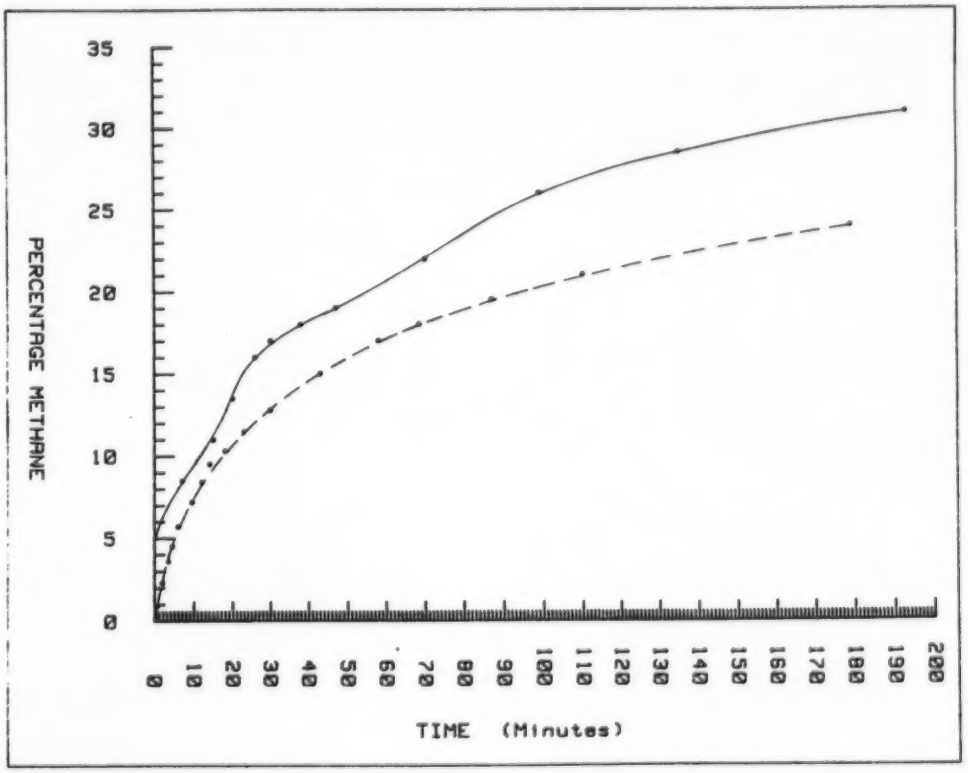
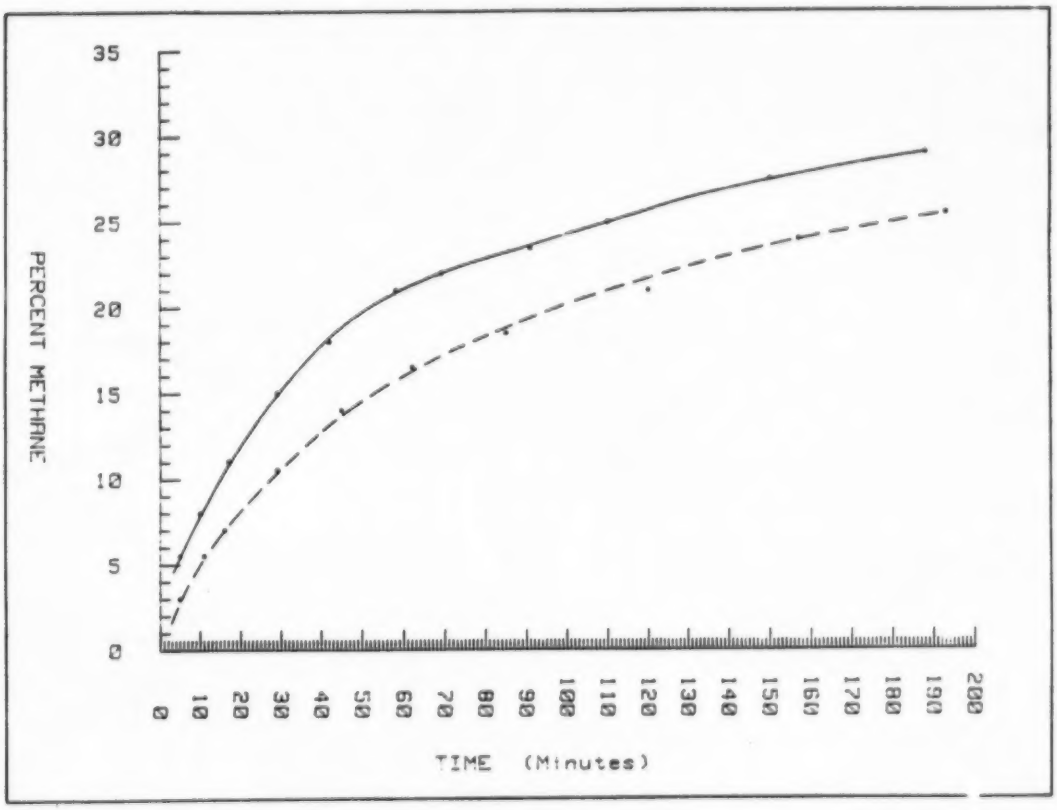


Fig. 10 - Comparison of predicted and measured methane concentrations within the coal pile of a raw coal silo (test 3)



- - - - Predicted
_____ Measured

Fig. 11 - Comparison of predicted and measured methane concentrations within the coal pile of a clean coal silo (test 4)



- - - - Predicted
_____ Measured

Fig. 12 - Comparison of predicted and measured methane concentrations within the coal pile of a clean coal silo (test 5)

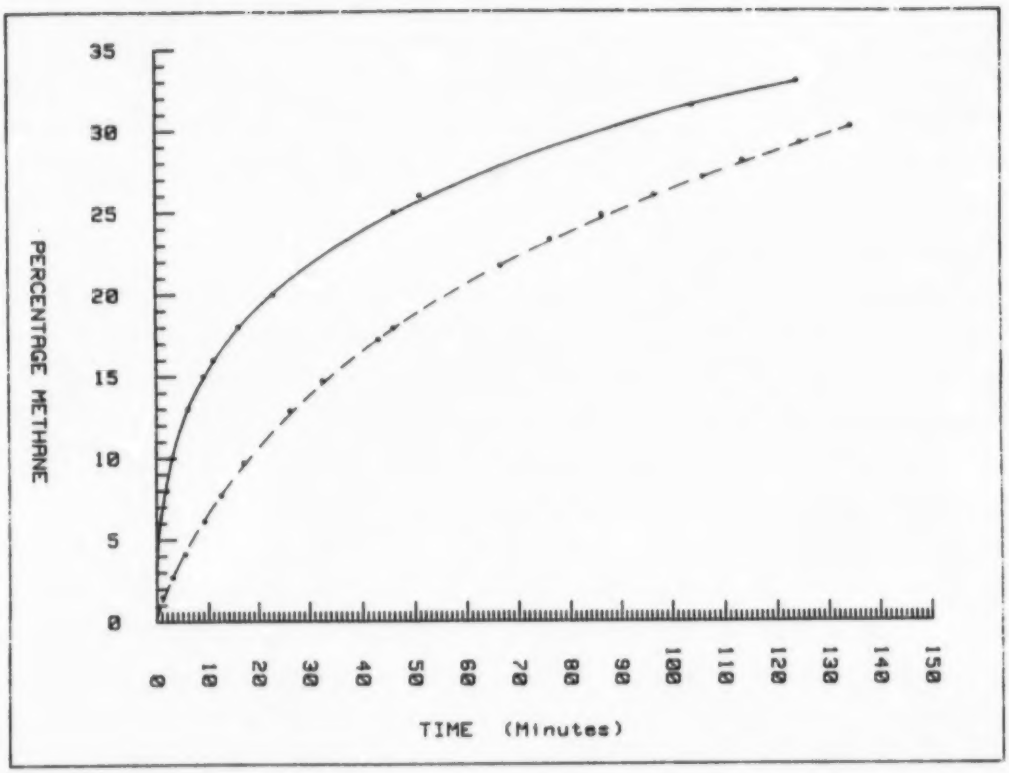


Fig. 13 - Comparison of the predicted and measured methane concentrations within the coal pile of a clean coal silo (test 6)

cool faster than coal within the silo, and this may cause a difference in the rate of methane emission from the sample to that from the coal in the silo. An attempt was therefore made to produce the same cooling rate of the coal in the sample container to that of the coal in the silo. This was done by diverting coal being conveyed to the silo into a large wheelbarrow into which the sample container was buried.

Figures 11 to 13 show the predicted methane concentrations in the coal pile using methane desorption data (dashed curve) and the actual measurements are shown as a continuous curve.

For these tests the sample tube was buried to depths of between 10-12 metres. The time taken to bury each tube was approximately 1-3/4 hours.

7.4. DISCUSSION OF RESULTS

Methane is flammable at concentrations between approximately 5-15% in air, and reaches a maximum explosive potential at a concentration of approximately 9.5%. By examination of Fig. 8 to 13 it is apparent that flammable concentrations of methane can occur within the coal pile of both the raw and clean coal silos that were tested. Such concentrations can also be found on the surface of the coal pile in clean coal silos when they are discharging.

There is a significant difference in the rate of accumulation of methane in the coal piles of the raw and clean coal silos. After, about one hour, a methane concentration of approximately 4% can be expected in the coal pile of the raw coal silos. In comparison a concentration of 20% or more may be expected in the coal pile of the clean coal silos after the same time period. The reason for this difference is due to the higher temperature of the clean coal after passing through the fluidized bed drier. The increase in temperature results in an accelerated rate of methane desorption from the coal and hence greater methane concentrations occur in the coal pile.

The accuracy of the predicted methane concentrations to those measured in the coal pile are initially inaccurate but improves with time. After say one hour, the predicted concentrations are only in error of those measured by approximately 20%. Therefore methane desorption data may be used to provide a useful indication of the methane concentrations that can be expected to occur in coal piles.

The predicted values of methane concentrations in the coal pile of the clean coal silos are consistently lower than those actually measured. This is probably due to the coal sample used in the methane desorption apparatus cooling faster than the coal inside the silo, despite the precautions taken. Therefore the accuracy of prediction may be improved in future testing by taking further steps to ensure that the cooling rates of the coal in the silo and the methane desorption testing sample are the same.

8. THE CALCULATION OF VENTILATION REQUIREMENTS FOR THE DISCHARGE GALLERY OF SILOS

Many silos are built side by side over railway lines forming a partially enclosed gallery into which unit trains enter for loading. Methane released into the gallery could present a hazard if the gallery is inadequately ventilated. Gallery ventilation requirements are normally determined by experience and by "rule of thumb". In the past this method of calculation has been found to be inaccurate.

The method described in this report for estimating the accumulation of methane within the coal pile of a silo could provide a more scientific and accurate means to calculate gallery ventilation requirements. This method is demonstrated below using values obtained from the Elkview processing plant.

The following data has been obtained from the plant operators.

Coal pile bulk density = 800 kg/m^3

Average coal density = 1360 kg/m^3

Peak silo discharge rate for loading a single car = 1021 kg/s

From figures 11 to 13 it can be seen that methane concentrations in excess of 30% were found in the coal pile of clean coal silos after a period of several hours. Consequently the air released from the silo upon discharging is assumed to have a methane concentration of 35%.

The percentage of free air space trapped within a coal pile is given by the expression:-

(1- (Bulk Density/Coal Density)) x 100%

= (1- (800/1360) x 100%

= 41%

Dividing the silo discharge rate by the coal pile bulk density gives the volume of coal pile released into the gallery in a given time i.e.

$1021/800 = 1.28\ m^3/s$.

Forty-one percent of this volume is trapped air having a methane concentration of approximately 35%. Hence the volume rate of methane discharged into the gallery is given by:-

$1.28 \times 0.41 \times 0.35 = 0.184\ m^3/s$.

The gallery ventilation flow rate (V) required to dilute the methane (M) to any desired concentration (C_2) is given by the equation:-

$$V = M(1/C_2 - 1/C_1) \quad m^3/s .$$

where C, is the original methane concentration. Assuming the methane is to be diluted to a concentration of less than 0.8% then:-

$V = 0.184(1/0.008 - 1/0.35) \quad m^3/s$
$= 22.5\ m^3/s$ which converts to 47,600 ft^3/min.

Until recently the discharge gallery at the Elkview plant was ventilated only by natural ventilation. This was found to be inadequate in preventing hazardous concentrations of methane from occurring during the discharging of coal from the silos. As a result the discharge area of three silos were each equipped with a 65,000 cfm exhausting fan and a fourth silo, which discharges onto a conveyor, was equipped with a 50,000 cfm forcing fan. Electrical equipment was modified to conform to the Canadian Standards Association Electrical Code Part 1, class 1, division 2, to prevent electrical sparking from providing a potential source of ignition. In addition to these measures a methane monitoring system was installed in the gallery with a total of 20 sensors which automatically trips out the power supply if a concentration of 1.25% is detected and gives an alarm at 0.8%.

Since the installation of these modifications the discharge operations in the gallery have conformed to the desired standard of safety.

By calculating ventilation requirements from measurements of methane concentration within the silo coal pile and applying a suitable factor of safety determined by experience, it is likely that gallery ventilation requirements can be estimated with far greater accuracy than in the past.

If future investigations can demonstrate that methane concentrations within silo coal piles can be predicted with suitable accuracy from small coal samples then preliminary estimates of discharge gallery ventilation requirements for new coal preparation plants can be calculated with relative ease. This test will also be useful for indicating whether gallery ventilation is adequate at existing preparation plants. However it should be emphasized that before this test can be considered to be reliable it must be validated by further investigations.

9. CONCLUSIONS

a) The ventilation systems of the silos tested were capable of rapidly dispersing any accumulations of methane in the atmosphere above the coal pile, except for a zone close to the coal pile surface in clean coal silos when they are discharging.

b) Ignitable concentrations of methane were found to occur inside the coal pile of both raw and clean coal silos. Methane concentrations inside the coal pile of clean coal silos were greater than in the coal pile of raw coal silos due to an accelerated release of methane from the coal after passing through the fluidized bed drier.

c) By obtaining a small sample of coal being conveyed to a silo and measuring the rate of methane released from it in a methane desorption apparatus, it is possible to predict the approximate methane concentrations likely to occur in the coal pile of a silo.

d) When a silo is discharging coal the air trapped in the coal pile will be released into the atmosphere. By knowing the volume of free air trapped in a coal pile and predicting the volume of methane released into this air space from methane desorption data, it is possible to calculate the rate of methane released into the atmosphere when the silo is discharging. From this knowledge it is possible to obtain an estimation of discharge gallery ventilation requirements.

10. RECOMMENDATIONS

Ignitable concentrations of methane have been found in coal storage silos. Such concentraions may occur in volumes large enough to cause destructive explosions by themselves, but even if they are small in volume they have the potential to initiate a coal dust explosion which can be very destructive. Therefore the following precautions are suggested:

a) Declare the silo top housing and discharge gallery as flame restricted areas while the silo contains coal in order to minimize the risk of ignition from sources such as smoking and welding.

b) To reduce the risk of ignition from silo electrical equipment such equipment could be modified or replaced to conform to the Canadian Standards Association Electrical Code for flammable gas environments.

c) It is possible that the equipment used for drying coal may become defective and produce very hot coals. This possible source of ignition has been cited as the most probable cause of a silo explosion which occurred in 1982 (1). A reliable instrument capable of detecting any object on the silo loading conveyor, of a temperature sufficient to ignite a flammable concentration of methane, and to turn off the conveyor automatically in such an event is recommended.

d) Installation of automatic methane alarms in silo discharge galleries.

e) Further investigations such as described in this report should be continued in Western Canada in order to assess the validity of using data from methane desorption tests of small coal samples to calculate discharge gallery ventilation requirements. Such investigations may also provide data to assess the risk of methane ignition to which silos in Western Canada are currently exposed.

11. ACKNOWLEDGEMENTS

The author wishes to express his thanks to Dr. R. N. Chakravorty for his advise and assistance and to Mr. H. Dennis (formerly Senior Inspector of Mines B.C.) for his initiation and interest in this project.

Grateful acknowledgement is made for the assistance and cooperation of the Elkview (Westar) management especially Mr. J. Palmer (Assistant Superintendent)

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